A "stochastic dynamics" method for ensemble seasonal forecasts with the CNRM-CM5.1 GCM

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Outline

Dynamical seasonal forecasting systems suffer from **insufficient spread** and **systematic errors**. We intend to address both issues by adding **stochastic perturbations** to prognostic variables of the atmospheric component of CNRM-CM5.1.
Perturbations are designed as **random corrections** of the atmospheric model **initial tendency errors**, estimated during a nudged integration of CNRM-CM5.1. **Optimal perturbations** (drawn within the current month of the hindcast period) show a potential for substantial improvements.

Stochastic dynamics method

The **stochastic dynamics** method (*Batté and Déqué, 2012*) is an additive stochastic perturbation technique. Prognostic variables T, q, and Ψ are perturbed by adding random draws of initial tendency error corrections of the ARPEGE-Climat v5.2 atmospheric component.

$$\mathbf{X}(t+\Delta t) = \mathbf{X}(t) + \mathbf{M}(\mathbf{X}(t), t) + \delta\mathbf{X}_t$$

The implementation follows three steps:

1. **Nudged 32-year run**: CNRM-CM5.1 model is nudged (τ = 1 day in the atmosphere) towards ERA-Interim reanalysis data (1979-2010).

2. **NDJF season nudged hindcast**: a four-member ensemble is run, starting from initial conditions of step 1 for Nov. 1979-2010, and nudged more lightly (τ = 1 month) towards ERA-Interim. Daily corrections toward ERA-Interim make up the $\{\delta\mathbf{X}\}$ population.

3. **Retrospective forecast** (no nudging !): starting from initial conditions of step 1, a seasonal re-forecast for each NDJF season is run, perturbing each member with random draws of $\delta\mathbf{X}$ terms within the calendar month (in cross-validation mode).

Atmospheric relaxation (nudging)

ARPEGE-Climat prognostic variables are **relaxed towards reference fields** with rate τ *(Jeuken et al., 1996)*.

$$\frac{\partial X}{\partial t} = M(X) + \frac{X^{\mathrm{ref}} - X}{\tau}$$

Differences between reference and model fields in a nudged run give an **estimate of the initial tendency errors** (*Guldberg et al., 2005*).

Re-forecasts and evaluation

The $\delta\mathbf{X}$ terms are selected by drawing a random date from the step 2 run, so that **perturbations are coherent for all variables and model levels**.

Several ensembles were run with **15 members** for **NDJF 1979-2010** and compared to ERA-Interim data (GPCP v2.2 data for precipitation) using deterministic (ensemble mean) and probabilistic scores:

INI : reference CNRM-CM5.1 ensemble with perturbations drawn only at the **initial time step** for each member.

SD RAND : a **random** $\delta\mathbf{X}$ **is drawn every 6 hours** during the run according to the calendar month.

SD SEQ5 : a **random sequence** of $\delta\mathbf{X}$ corresponding to **5 consecutive days** of the hindcast period is drawn every 5 days.

MONM : the **time average** of $\delta\mathbf{X}$ for **all other years of the re-forecast period** and the current month is added at each time step.

SD OPT (« optimal perturbations ») : a **random** $\delta\mathbf{X}$ is drawn within the **current month** and year of the re-forecast. Impossible in real-time !

Main results

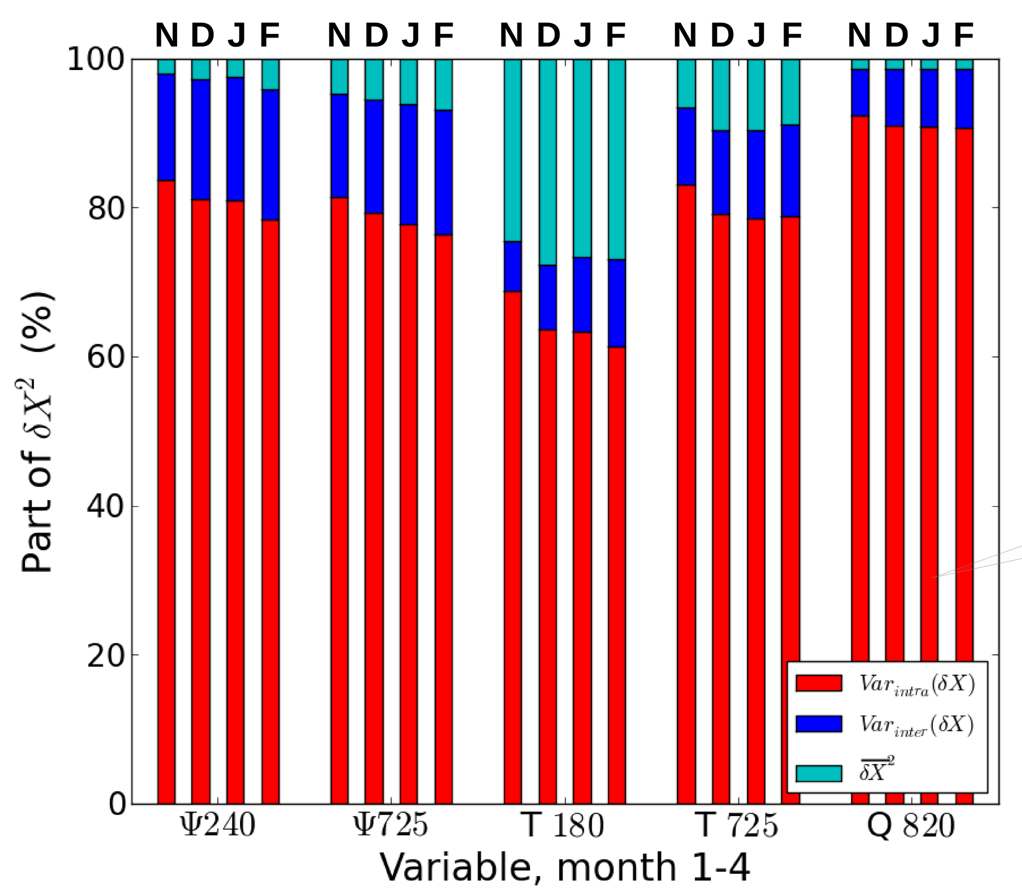

Fig 1 : Decomposition of mean correction terms over the re-forecast period for prognostic variables at several model levels, according to lead-time (NH average).

Mean($\delta\mathbf{X}^2$) = Mean² + Var (inter) + Var (intra)

Decomposition of mean square correction terms shows that **intra-month variance** explains most of the $\delta\mathbf{X}$ variance, but the other two terms cannot be neglected.

Mean bias for 500 hPa geopotential height **is reduced** when monthly mean or random correction terms are introduced.

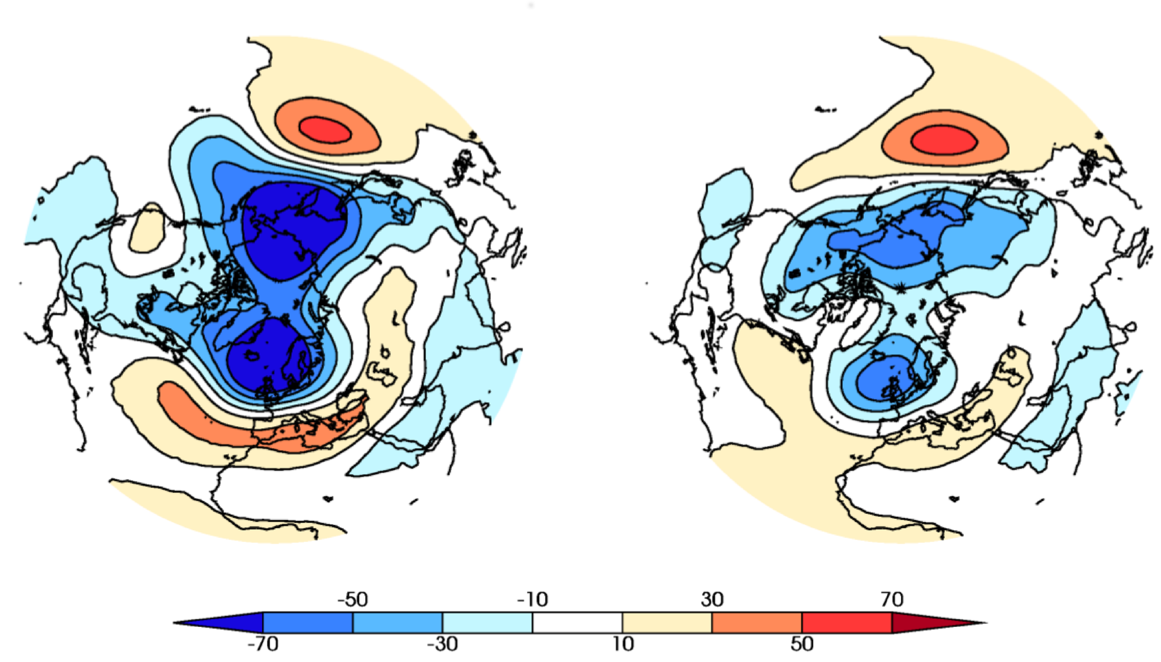

Fig 2 : Mean bias (in meters) for DJF Northern Hemisphere Z500 for runs INI (left) and SD RAND (right). All SD and MONM ensembles have similar bias for NH Z500.

Anomaly correlation scores are **improved for NH Z500** and precipitation over the Tropics; RPSS is **unchanged**. DS OPT results show valuable information is contained in corrections at a monthly time scale over mid-latitudes.

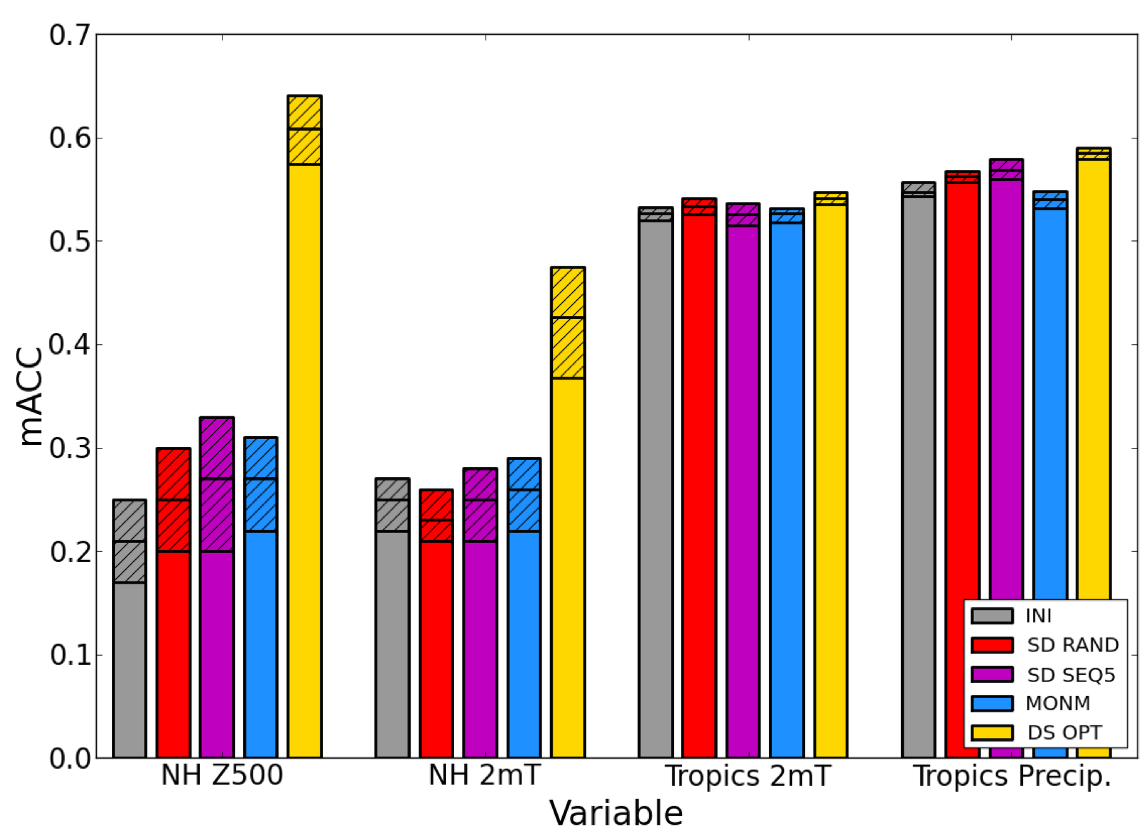

Fig 3 : Mean ACC for DJF 1979-2010 re-forecasts with respect to ERA-Interim (for Z500 and T2m) and GPCP v2.2 (for precipitation). Dashed boxes show the 5%-95 % range and average of scores for random draws of 9 out of 15 ensemble members. NH is for latitudes from 30°N to 75°N.

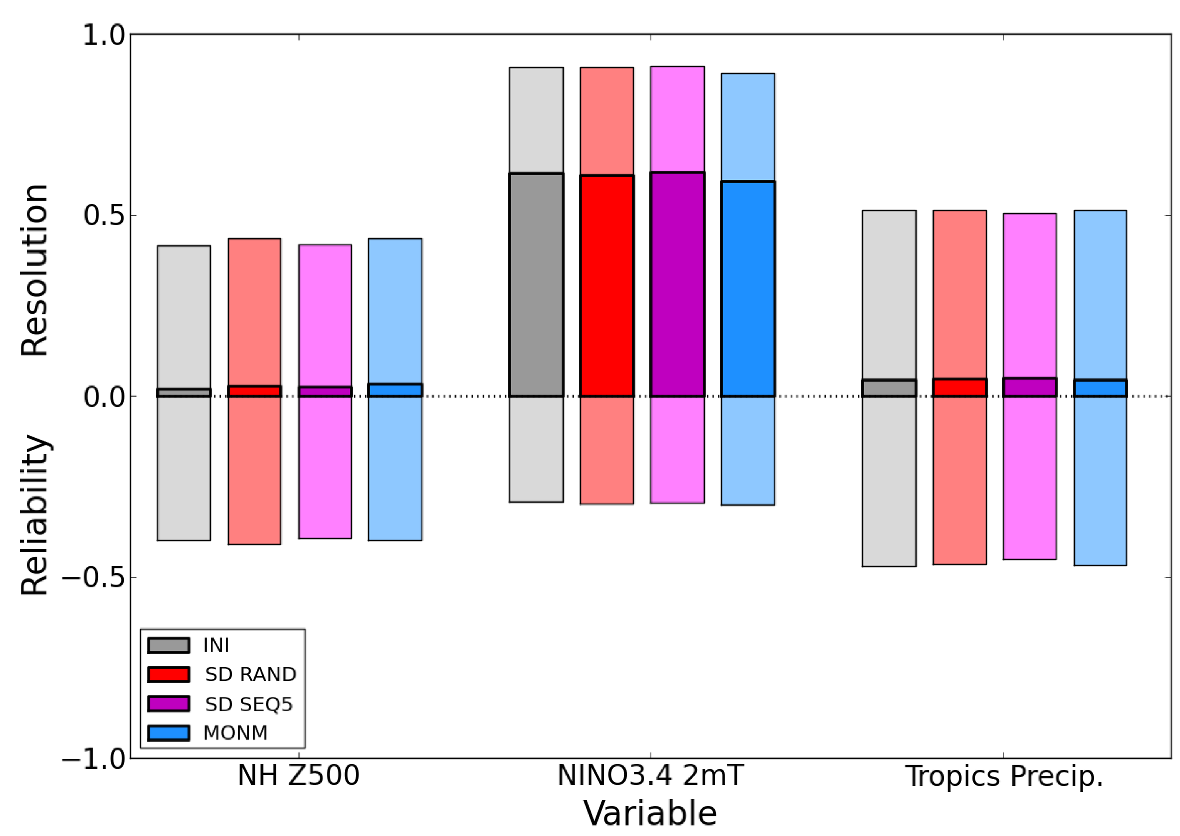

Fig 4 : RPSS (*Epstein, 1969*) and reliability – resolution decomposition for 1979-2010 DJF re-forecasts of NH Z500, Niño3.4 2m temperature and precipitation over the Tropics.

Future work

- Sensitivity to the variables and time scales used for nudging during steps 1 and 2 will be assessed.
- State-dependent $\delta\mathbf{X}$ corrections *(D'Andrea and Vautard, 2000)* could be a way to improve model performance, but tests using Niño 3.4 SST or global streamfuncion as classification criteria have not been conclusive.
- Are results model-dependent ? Current work at IC3 aims to implement this method in the IFS component of EC-Earth v3.

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